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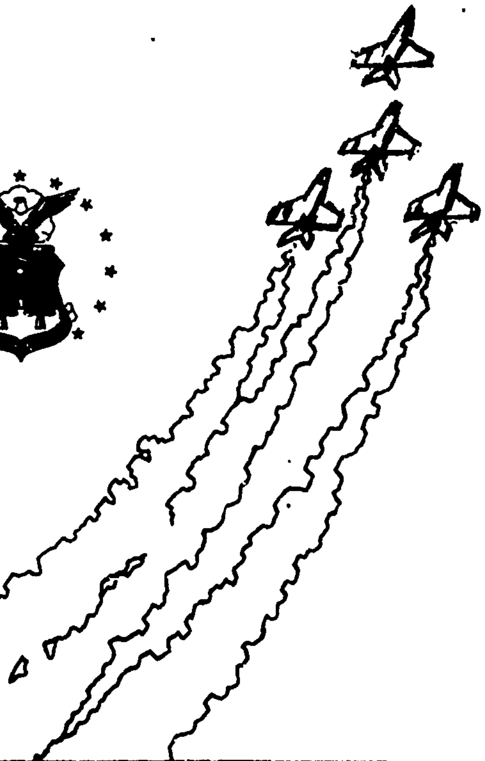

DFAN TR 72-3

A DESCRIPTION OF THE DFAN BIDIRECTIONAL REFLECTOMETER AND BIDIRECTIONAL REFLECTANCE CHARACTERISTICS OF STAINLESS STEEL 304

Leo W. Stockham, Major, USAF

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13. ABSTRACT

The characteristics of the bidirectional reflectometer designed, constructed, and operated in the Department of Aeronautics, USAF Academy are described and discussed. The reflectometer is shown to be an adequate device for studying reflectance of thermal radiation from prepared engineering surfaces. Data obtained from two samples of stainless steel 304 is presented.

Details of illustrations in this document may be better studied on microfiche

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TECHNICAL REPORT DFAN TR 72-3

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Foreword

The work reported herein is jointly sponsored by the Air Force Weapons Laboratory and Frank J. Seiler Research Laboratory under project AFWL-72-006 and FJSRL 7905-00-23.

The results presented were obtained by Major Leo W. Stockham, Tenure Associate Professor of Aeronautics, Department of Aeronautics, USAF Academy, Colorado and by the following USAF Academy cadets:

Cadet A. C. McLellan	Class of 1971
Cadet D. S. Gracey	Class of 1972
Cadet R. C. Emerick	Class of 1972

The work was accomplished during the period January 1971 through July 1972 at the USAF Academy and the manuscript was submitted for publication 31 July 1972.

This technical report has been reviewed and is approved.

R. N. James

R. N. JAMES, Major, USAF
Research Coordinator

D. H. Daley

DANIEL H. DALEY, Colonel, USAF
Professor and Head

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Introduction

The bidirectional reflectometer was designed to support research in radiative characteristics of surfaces under sponsorship of the Air Force Weapons Laboratory and Frank J. Seiler Research Laboratory. The instrument permits measurement of reflected thermal radiation, as a function of angle of incidence, angle of reflection and wavelength, from prepared engineering surfaces.

This report describes the reflectometer, its performance capabilities, and presents reflectance data on two stainless steel 304 surfaces.

General

A schematic of the general layout of the reflectometer is shown in Figure 1. Thermal radiation from a globar source is collected by front surface spherical mirror A and focused on the sample surface. Rotation of the sample about a vertical axis at the surface provides the capability to vary the angle of incidence θ_1. With θ_1 set, the globar, mirror A, and the sample can be rotated about the same vertical axis to vary the angle of reflectance θ_2.

The reflected radiation is collected by front surface spherical mirror B and focused on the entrance slit of the monochromator. The monochromator is a standard Perkin Elmer model 99 Double Pass instrument with an NaCl prism and a thermocouple detector. The output of the monochromator is an electrical signal proportional to the energy falling on the entrance slit in the wavelength band selected. This signal is then amplified and recorded. A signal proportional to the incident radiation can be recorded by setting θ_1 and θ_2 equal to 90 degrees and retracting the sample. Limited out of plane measurements can be made by rotating the sample about a horizontal axis at the sample surface.

External Optics

Mirrors A, B, and C are shown mounted in Figure 2. A is a gold coated front surface spherical mirror, 4.25 inches in diameter with a radius of curvature of 22.05 inches. It subtends a solid angle of .0319 steradians.

B is aluminum coated with a silicon monoxide overcoat. It is a front surface spherical mirror 4.25 inches in diameter, radius of curvature of 43.3 inches and solid angle of .00758 steradians. C is gold coated, 6 inches in diameter and flat.

The bend in the optical path (shown in Figure 1) produced by mirror C introduces coma aberration which gives a 1" by 1/4" image at the monochromator entrance compared to 3/4" by 1/4" image at the sample position. Since the entrance is masked to 1/2" by 7/32" and the slit opening is less than 2 mm in the 7/32", this aberration is not considered a serious defect.

Source and Sample Assembly

The source and sample assembly is shown in Figures 2 and 3. The source is a globar mounted in a water cooled housing and is rigidly attached to an optical bench mounted on a rotating table. The sample holder is mounted on the same optical bench but has independent degrees of freedom in translation and rotation. The translation provides a micrometer adjustment for placing the axis of rotation in the plane of the sample face. The rotational freedom is the angle of incidence. The angle of reflection is varied with the rotating table. The rotating table can be turned manually or automatically by an electric motor. In the automatic mode the angle of reflection is varied by discrete steps of .5 degrees every 12 seconds.

Detector Assembly

The detector assembly consists of the monochromator and associated thermocouple, amplifiers and recorder. These are standard components of the Perkin Elmer 112 U spectrometer. The monochromator is mounted on a rotating and translating table to provide accurate positioning adjustments. The assembly is shown in Figure 4. The monochromator schematic is given in Figure 5.

Performance Capability

To evaluate the performance capability of the reflectometer a number of tests were conducted. Calibration of the monochromator was accomplished during the spring semester 1971 by Cadet A. C. McLellan as an Aero 499 independent research project. The calibration curve prepared from his report is presented as Figure 6.

The amplifier design is such that step changes are made in amplification by a switch on the control panel. To calculate reflectance from data obtained at different gain settings it is necessary to know the amplification change between settings. This information and checks of the angle measurement capability using diffraction gratings were obtained during the fall semester by Cadet D. S. Gracey. Information from his report[2] is presented in Table 1 and Figure 7.

During the spring semester 1972 reflectance measurements were made on a standard specimen obtained from the National Bureau of

Standards. The data obtained is compared with the standard in Figure 8.

In instruments of this kind it is necessary to use mirrors which collect enough energy to be detected. Finite mirrors necessarily mean finite solid angles in the radiation measurements and hence some modification in interpreting the data obtained. Figure 9 shows the specular peak obtained at 45 degrees for this system. The dashed curve is the theoretical peak for an infinitessimal collecting mirror. The solid line is based on the geometry of the system.

From the information presented in Figure 6 through 9 and Table 1 it seems reasonable to conclude that the system operates properly and can be used reliably in the investigation of radiative properties of surfaces. The accuracy of the data obtained is of the order of one degree in absolute angular measurement and, depending on the range of gain settings employed, a few percent in absolute reflectance. Relative measurements are more accurate.

As currently configured the system is limited to wavelengths from about 1 to 15 microns. Addition of a detector for visible radiation and a laser source in the IR region is planned to permit comparison of data using coherent and non coherent sources.

Some experimental data is presented as an illustration of capability in the next section.

Experimental Results

To demonstrate the capability of the reflectometer a limited study of two samples of stainless steel 304 was undertaken. The samples were cut from 1 1/2" bar stock, milled to a thickness of 1/4" and polished using standard techniques. One sample was then roughened by sandblasting with Al_2O_3 grit size 240. The data was taken at room temperature.

Figure 10 shows the absolute reflectance obtained for the polished sample and compares the data with results for similar materials as reported in the literature[3, 4]. The agreement is satisfactory.

Reflectance data on the roughened sample is presented in Figures 11 through 13. The dip at - 60 degrees for the $\theta_1 = 60^\circ$ curve in Figure 11 is due to blockage of the collection mirror by the source to sample optics. Blockage occurs in all cases but was not plotted to simplify the graphs. The relative reflectance plotted is defined to be the ratio of the reflectance in the direction θ_2 to the maximum reflectance in the plane containing the surface normal and the direction of incidence, i.e. the specular plane. The figures

clearly show the decrease in off specular shift of the peak radiation and the trend toward specular reflection expected with increasing wavelength.

The rms roughness of the sample surfaces was measured mechanically using a Bendix Profilometer and calculated from experimental data for the roughened surface using the expression of Davis[5]. The results are presented below.

Specimen	RMS Roughness Mechanical	RMS Roughness Optical
polished	$.03 \pm .005\,u$	———
roughened	$1 \pm .1\,u$	$.988\,u$

Figure 14 shows the specular nature of the polished sample at 10 microns and Figure 15 illustrates the variation of the angular distribution with wavelength for a fixed angle of incidence.

Conclusions

The operation of the reflectometer has been demonstrated and its accuracy verified by comparing data obtained with it and data from standard samples and that published in the literature. This has been done to insure the validity of using the device in further studies with new materials. In addition, a limited amount of new data on stainless steel 304 has been presented.

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1. Cadet 1/C A. C. McLellan, "Calibration of the Perkin Elmer Model 99 Double Pass Monochromator," Aero 499 Report, May 1971.

2. Cadet 1/C D. S. Gracey, "Determining the Reliability of an Existing Reflectance Measuring System," Aero 499 Report, Dec 1971.

3. Love, T. J., Radiative Heat Transfer, Merrill, 1968.

4. Sparrow, E. M. and Cess, R. D., Radiation Heat Transfer, Brooks Cole, 1966.

5. Beckman, P. and Spizzichino A., The Scattering of Electromagnetic Waves from Rough Surfaces, Macmillan, 1965.

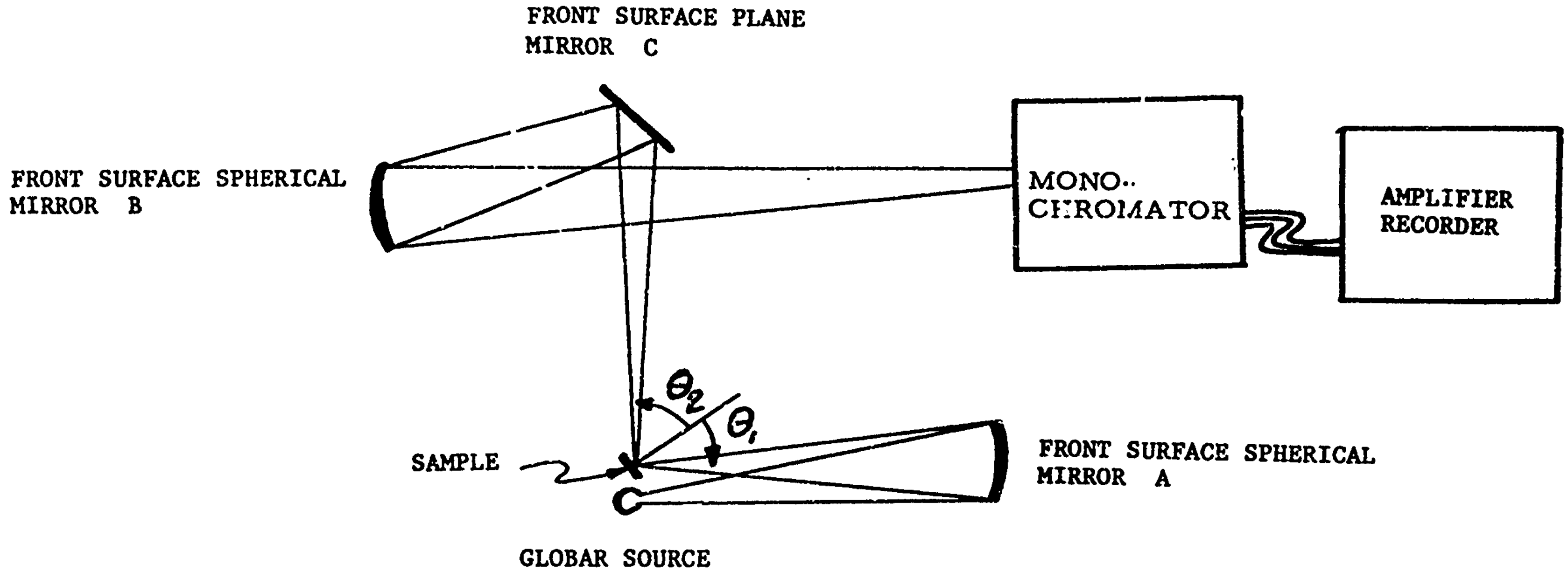


FIGURE 1. The general layout

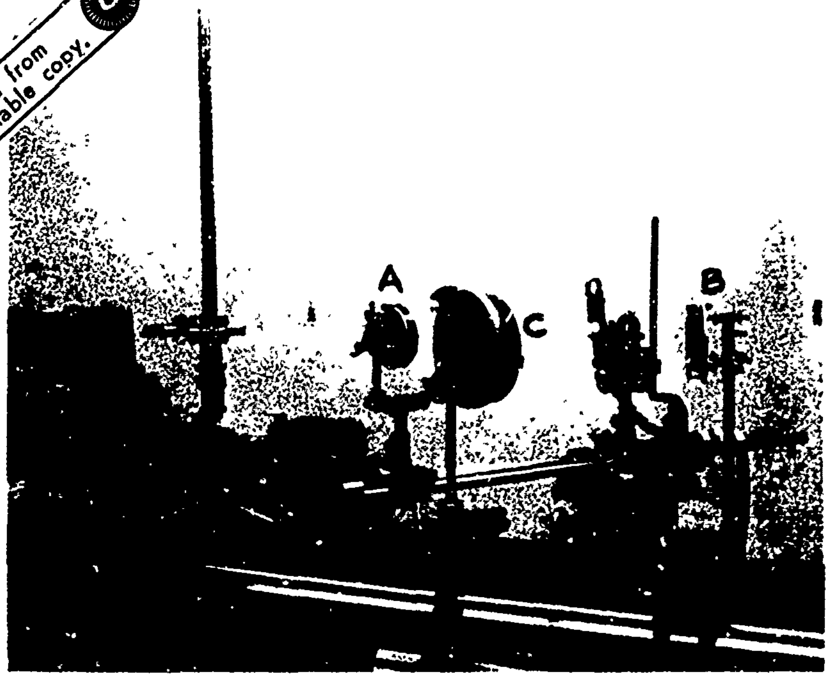


FIGURE 2. External assembly

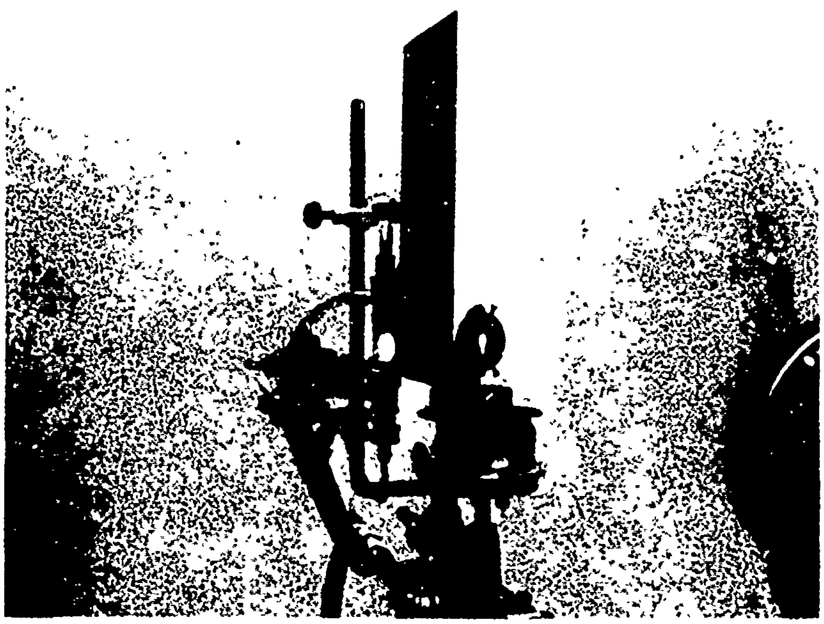


FIGURE 3. Source and sample assembly

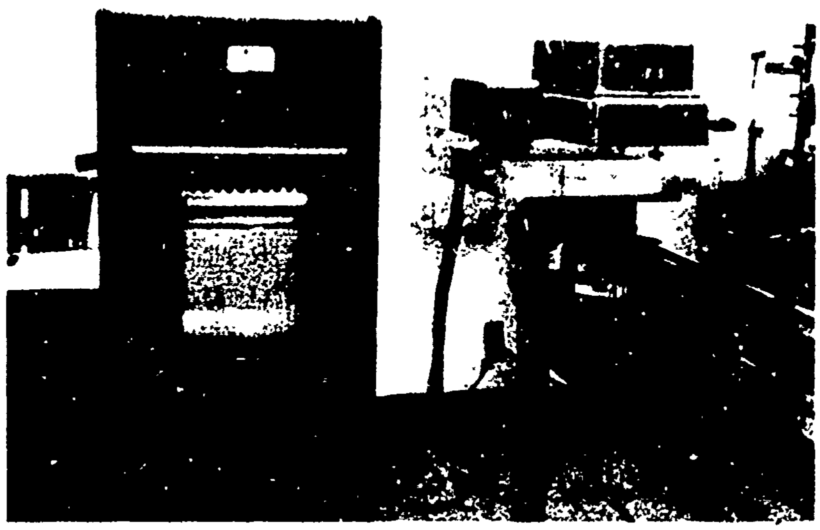


FIGURE 4. Detector assembly and console

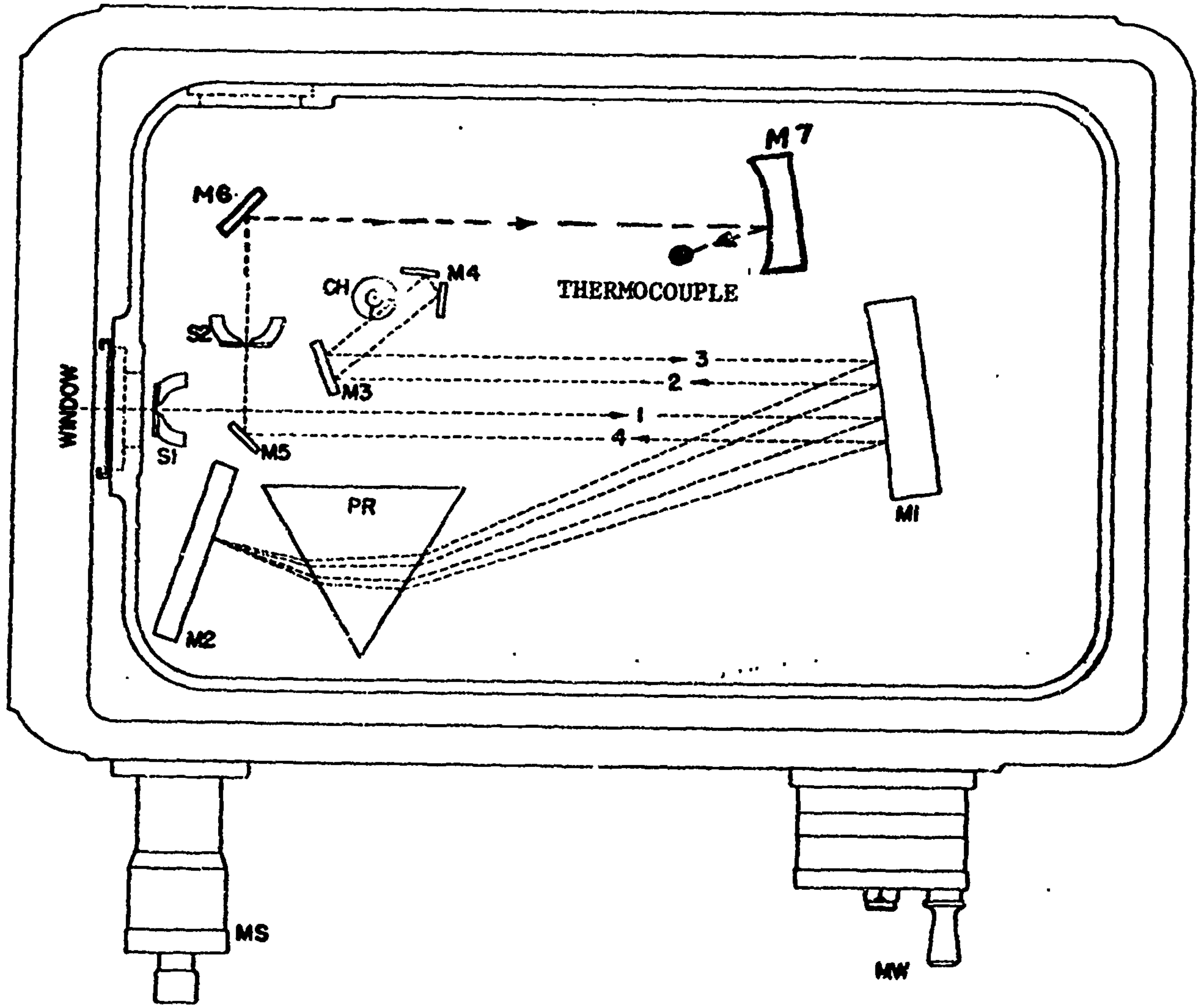


FIGURE 5. The monochromator

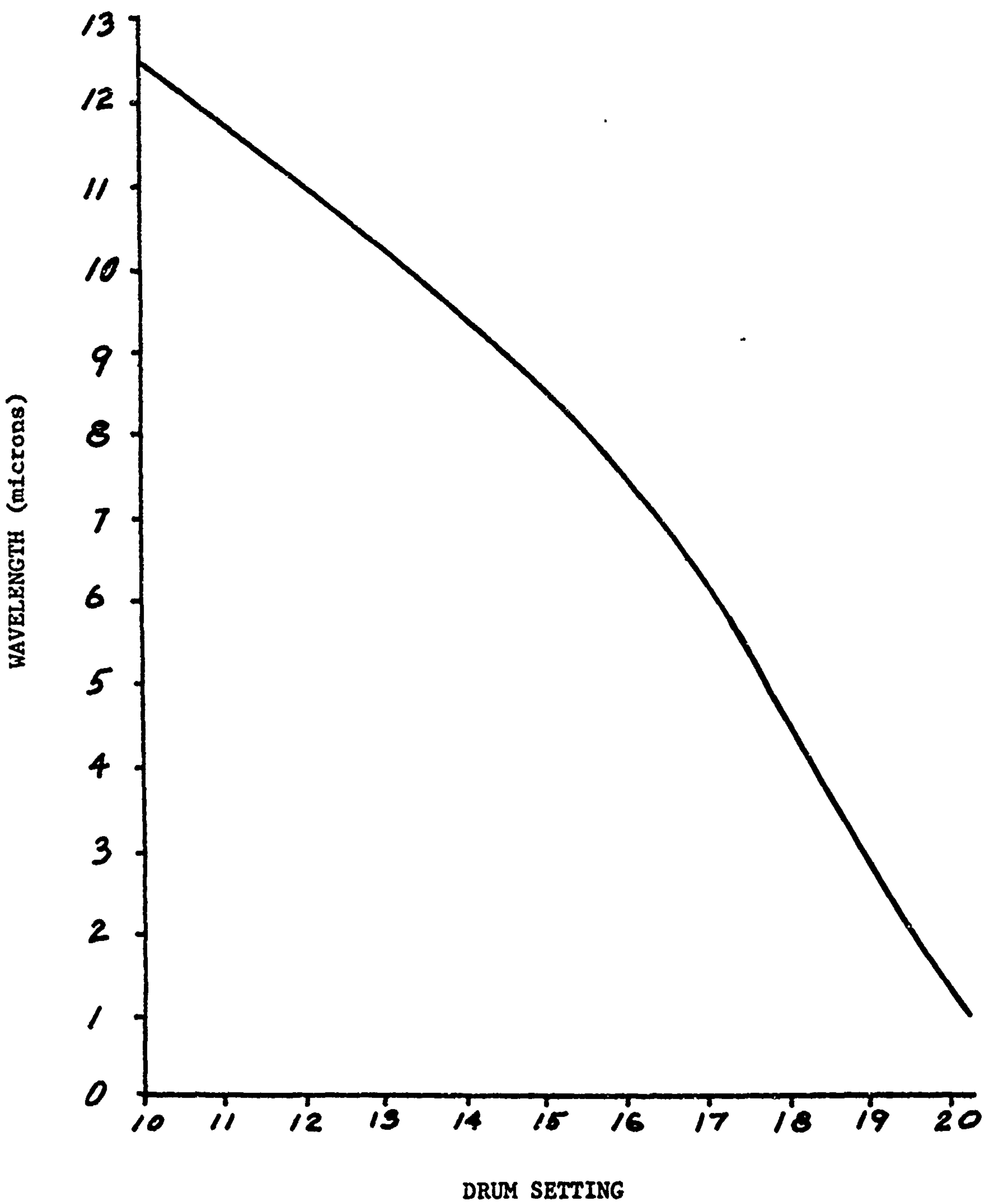
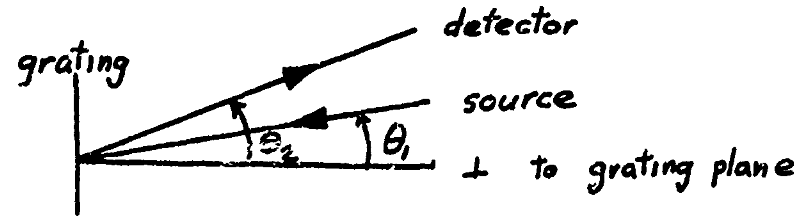


FIGURE 6. Calibration curve for the monochromator



$d\,(\sin\theta_1 + \sin\theta_2) = m\lambda$

$\lambda = 4\ \mu$, $d = 7.06\ \mu$

d ≡ spacing
m ≡ order
λ ≡ wavelength

θ_1	m	θ_2 (Theory)	θ_2 (Observed)
20	0	- 20	- 20.5
	- 1	- 65	- 65.3
30	0	- 30	- 30.5
	1	- 3.8	- 3.5
45	0	- 45	- 46
	1	- 8.1	- 9.5
	2	25.2	25.2
60	0	- 60	- 59.2
	1	- 17.4	- 16.8
	2	15.4	15.8

FIGURE 7. Diffraction grating data

Change	Factor	Change	Factor
2-3	1.53	9-10	1.57
3-4	1.57	10-11	1.56
4-5	1.56	11-12	1.58
5-6	1.59	12-13	1.54
6-7	1.56	13-14	1.56
7-8	1.56	14-15	1.52
8-9	1.59	15-16	1.50

Table 1. Amplifier gain setting multiplication factors

Wavelength (microns)	Reflectance			
	Standard		Measured	
	ρ	σ_m	ρ	σ_m
1	.979	.0026	.979	.0041
2	.988	.0063	.988	.0037
3	.988	.0058	.985	.0033
4	.988	.0090	.985	.0051
5	.988	.007	.984	.0047
6	.988	.007	.989	.002
8	.989	.0053	.990	.001
10	.989	.0053	.989	.003
12	.989	.0053	.985	.006

ρ ≡ reflectance

σ_m ≡ standard deviation from mean

Figure 8. Gold standard reflectance data

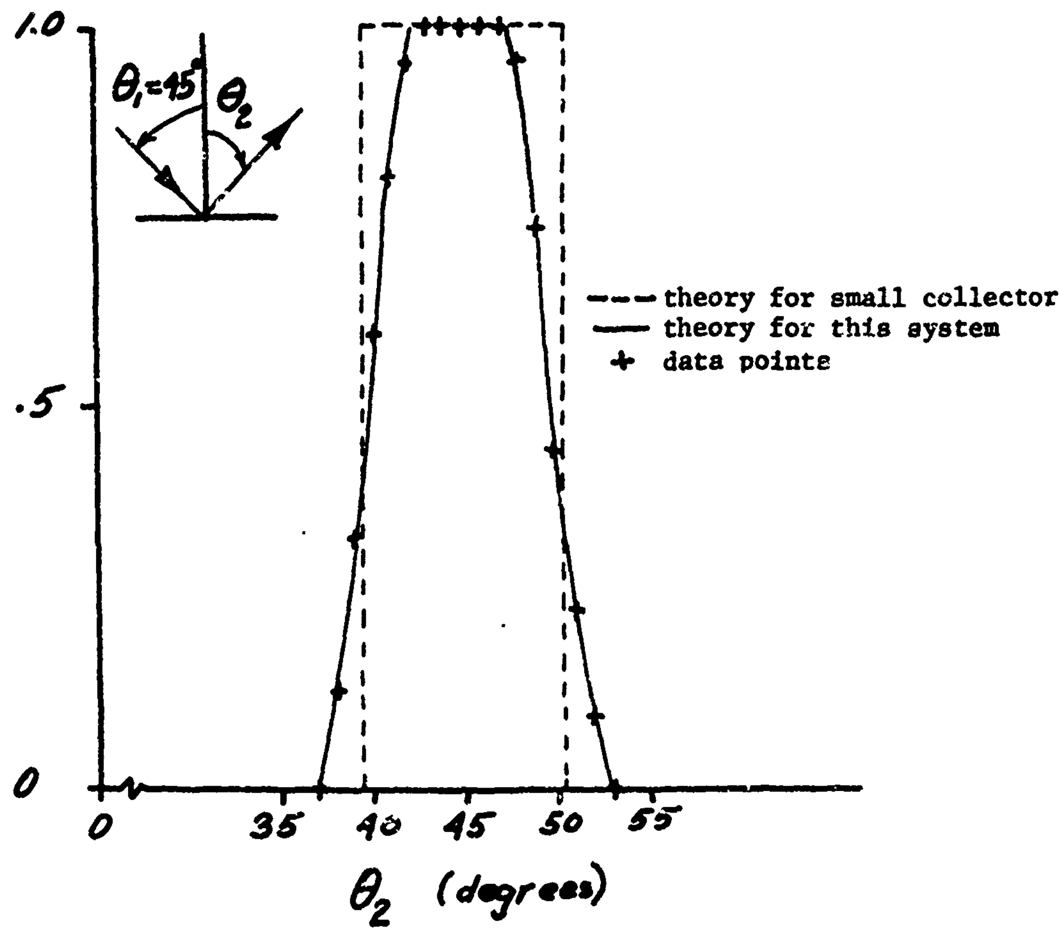


FIGURE 9. The specular peak

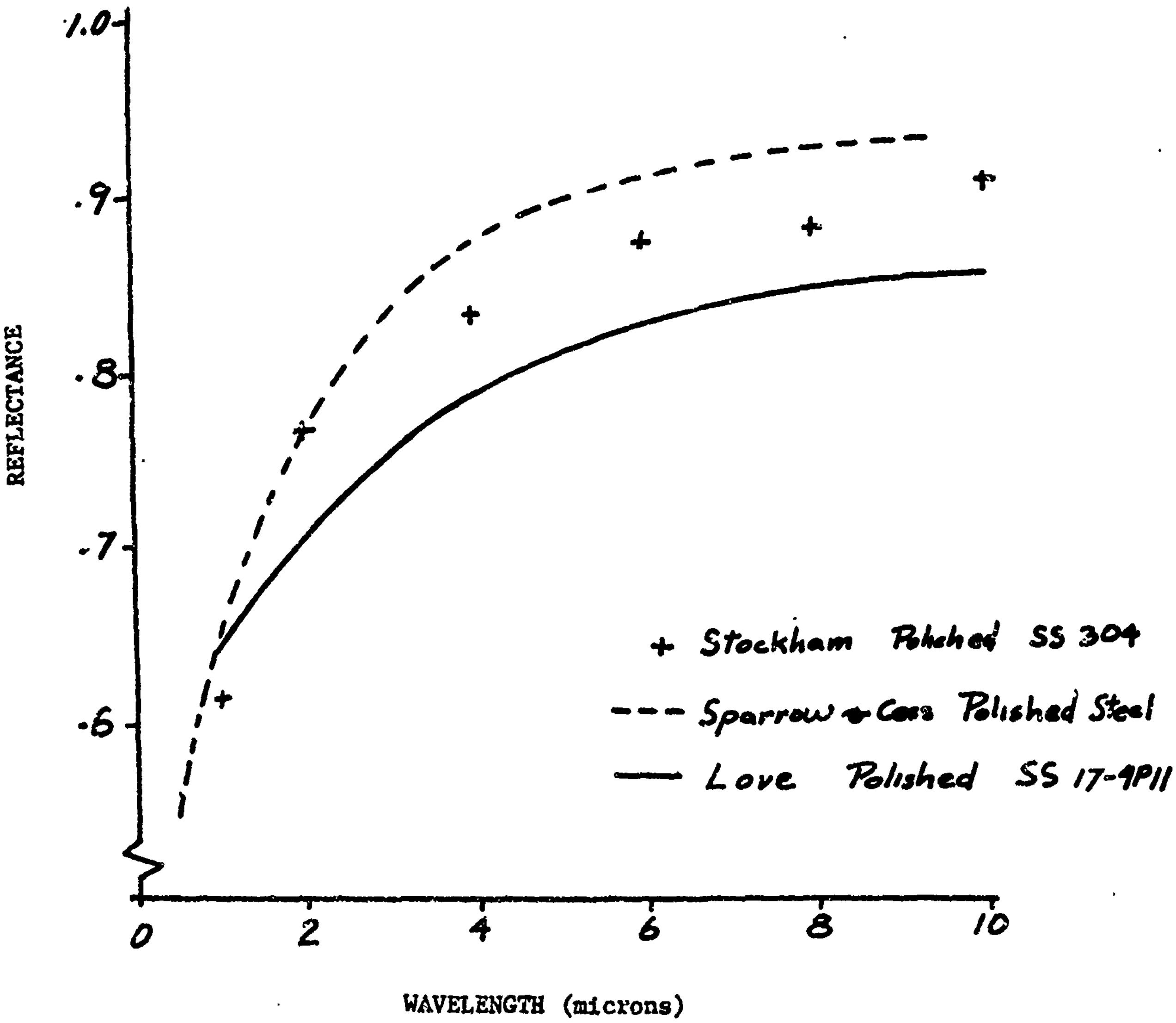


FIGURE 10. Spectral near normal specular reflectance of polished steel

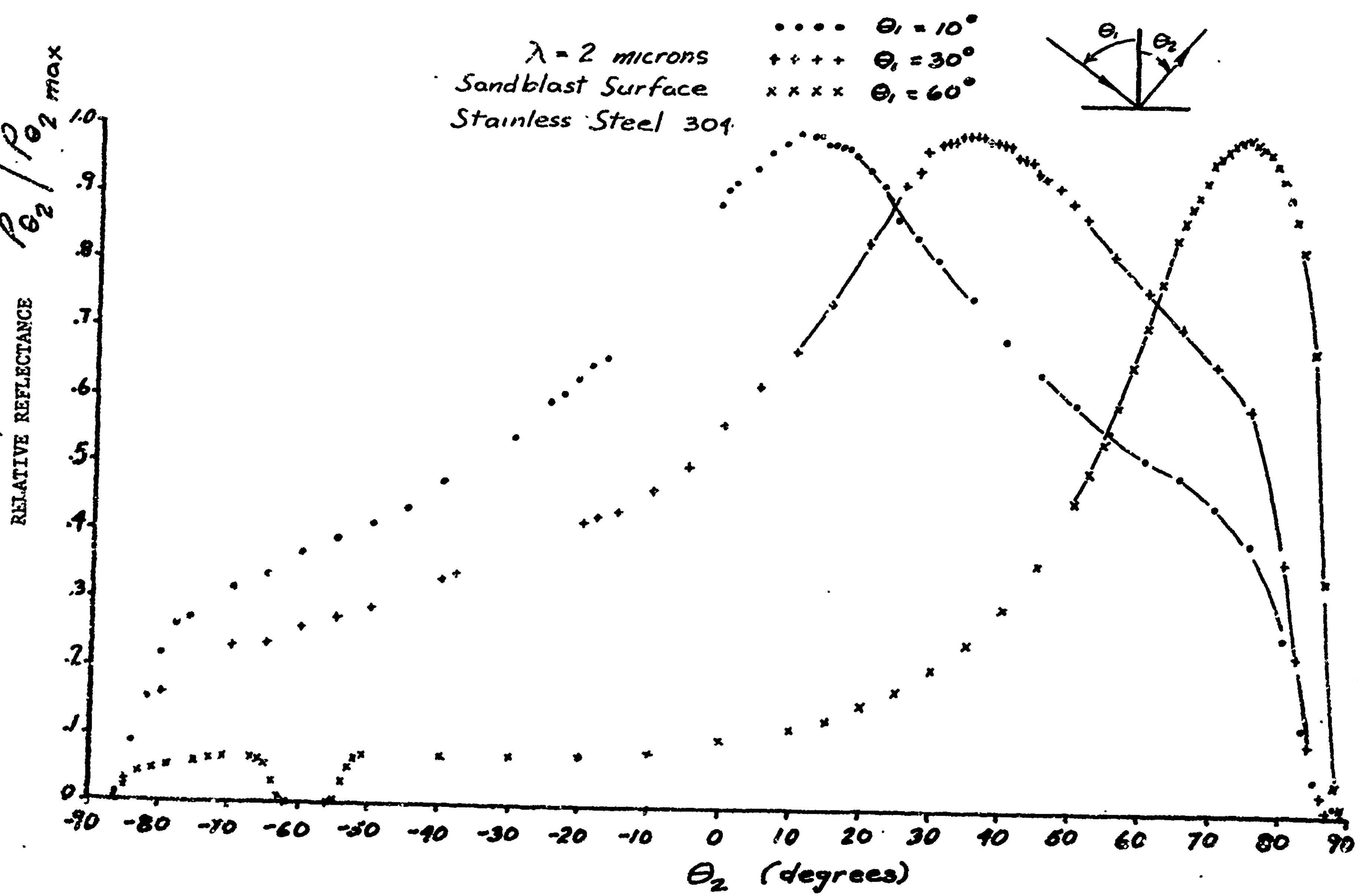


FIGURE 11. Angular depdence of relative reflectance at 2 microns

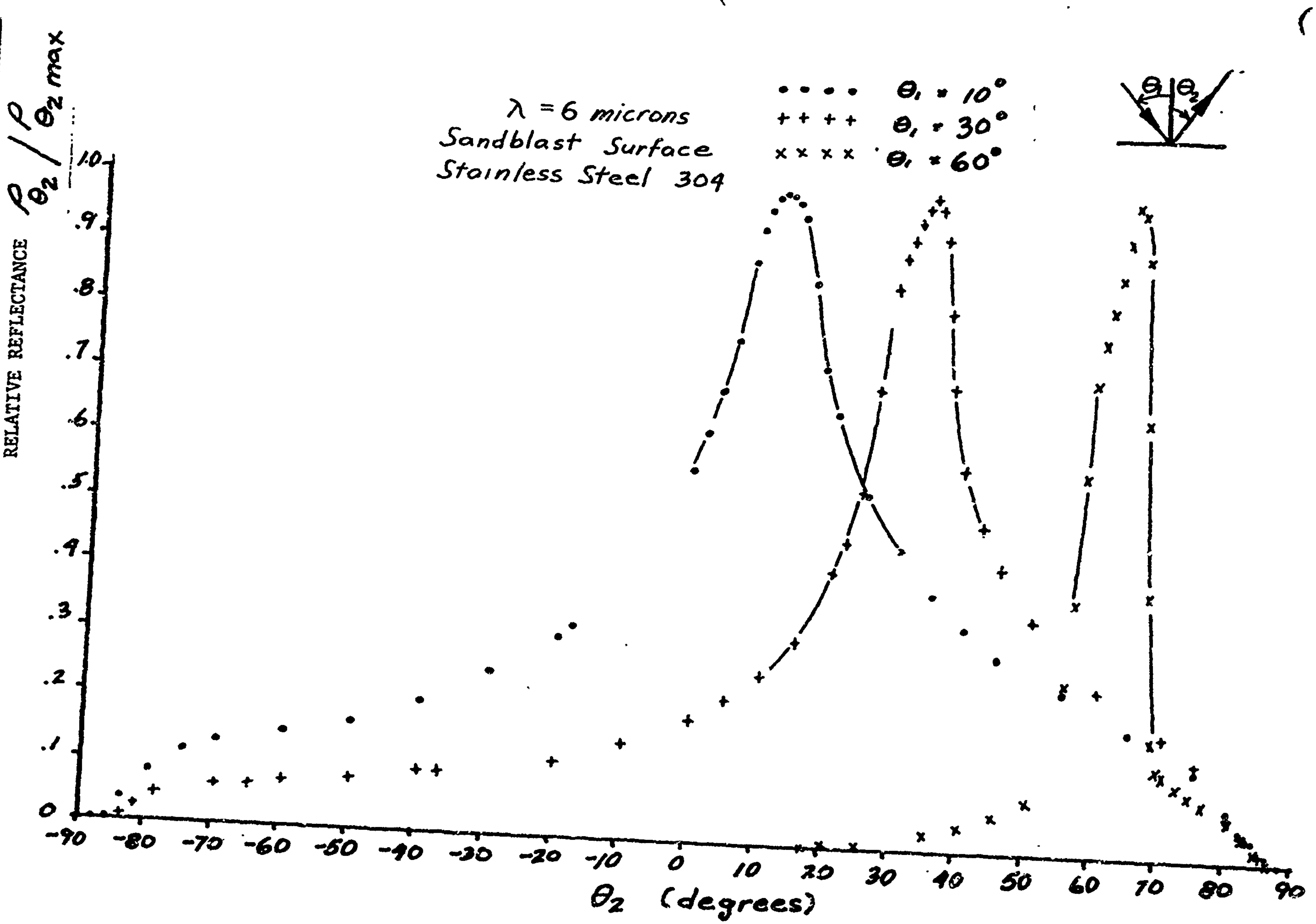


FIGURE 12. Angular dependance of relative reflectance at 6 microns

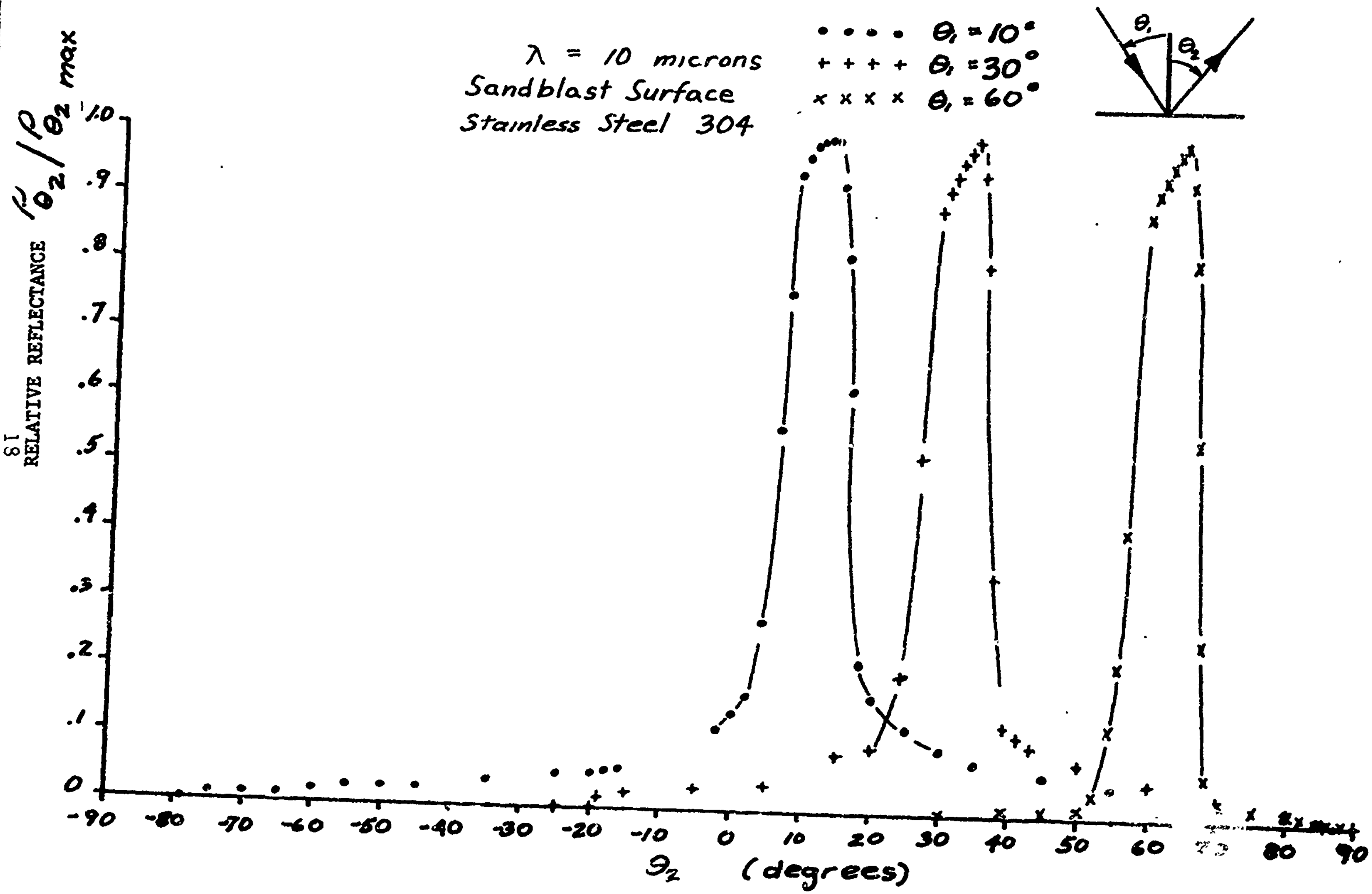


FIGURE 13. Angular dependance of relative reflectance at 10 microns

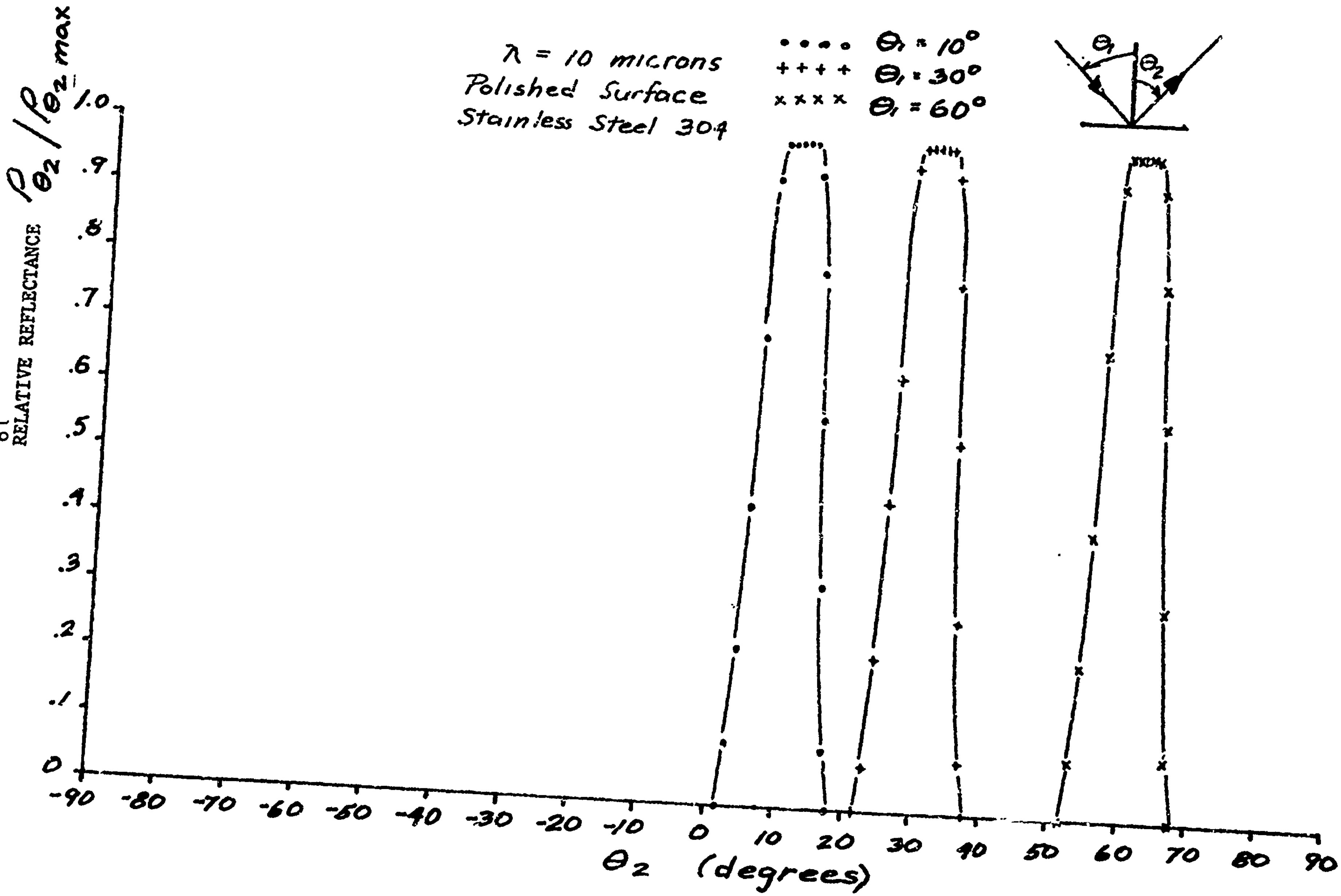


FIGURE 14. Angular dependance of relative reflectance at 10 microns for a polished surface

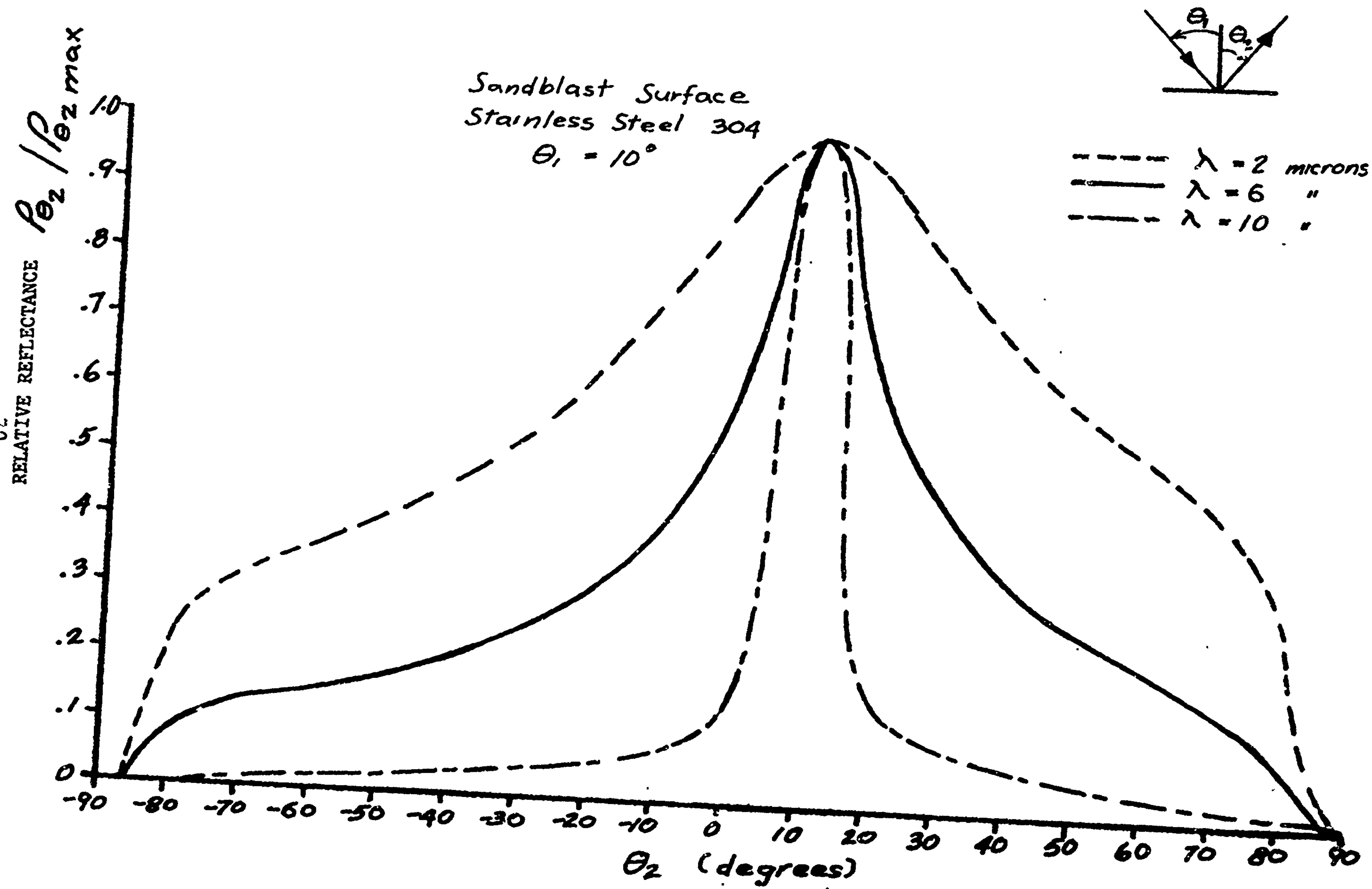


FIGURE 15. Relative reflectance of sandblast surface at an angle of incidence of 10 degrees